May 3, 1932. E. T. BURTON 1,856,373

POWER AMPLIFIER

Filed July 19, 1928 2 Sheets-Sheet 1

FIG. 1

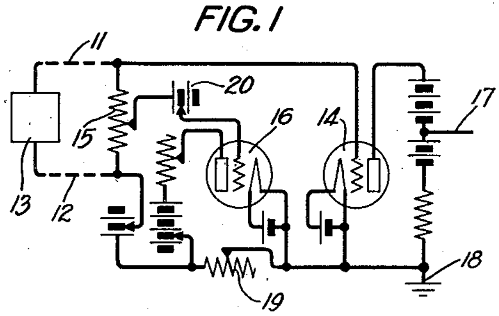


FIG. 2

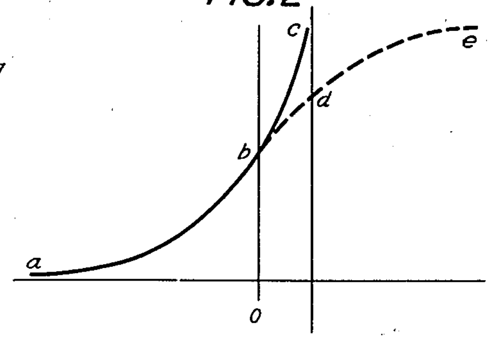


FIG. 3

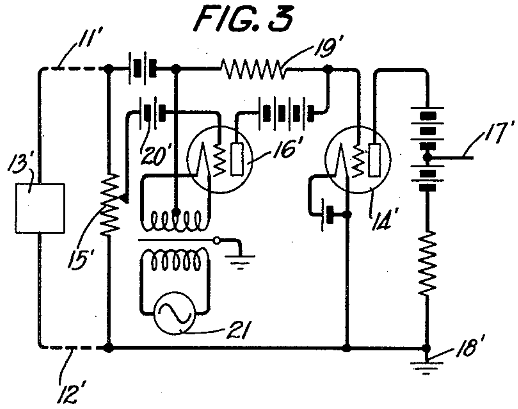


FIG. 4

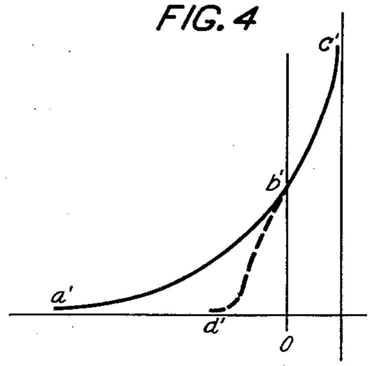


FIG. 6

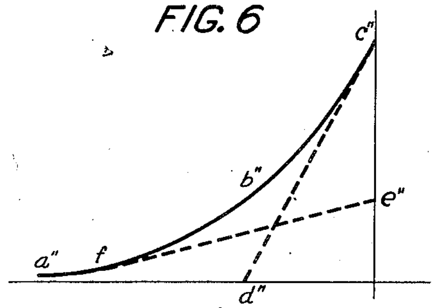
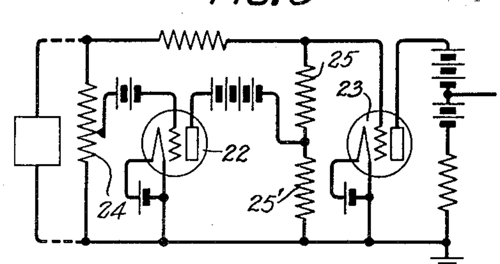
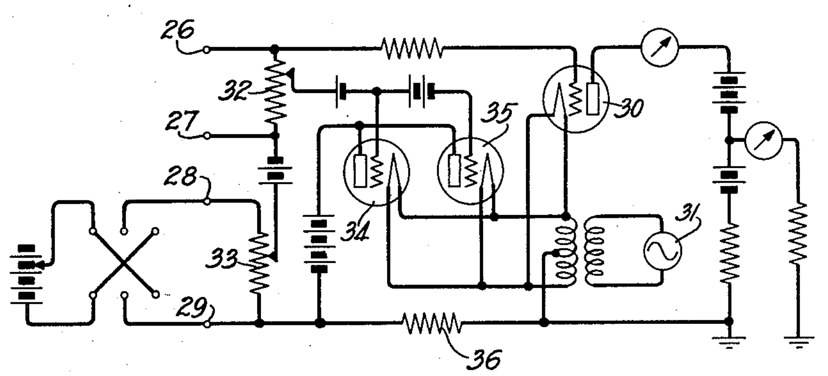


FIG. 5



INVENTOR
EVERETT T. BURTON
BY
J. W. Schmied
ATTORNEY

FIG. 7



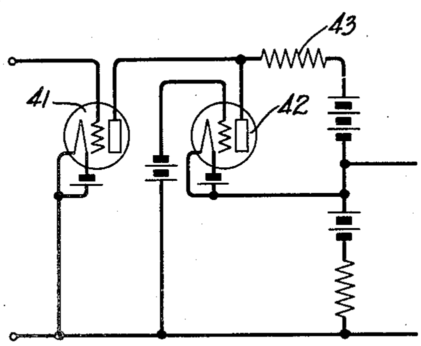


FIG. 8

INVENTOR
EVERETT T. BURTON
BY J. W. Schmied
ATTORNEY

Patented May 3, 1932

1,856,373

UNITED STATES PATENT OFFICE

EVERETT T. BURTON, OF MILLBURN, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

POWER AMPLIFIER

Application filed July 19, 1928. Serial No. 293,815.

This invention relates to electric wave repeating apparatus and particularly to the use of electron discharge amplifiers for repeating and amplifying signals for transmission.

An object of the invention is to compensate for the distortion introduced in the outgoing signals by operating a vacuum tube amplifier circuit to its full power output whereby the normal ratio of the output impedance of the tube and its connected circuit is departed from during portions of the time.

It is well known in the art that if external impedance in the output circuit of a vacuum tube amplifier is greater than the plate resistance, the characteristic of the amplifier becomes nearly linear when the amplifier is operated at low signal amplitudes, thereby rendering the output signal waves practically distortionless. It is also generally known in the art that this reduction in curvature of the characteristic may be enhanced by adding a series resistance in the output circuit of the vacuum tube. When it is desired to operate a vacuum tube at high power efficiency, it is necessary that the load impedance be matched to the impedance of the tube and that any added resistance be very small or eliminated entirely. The characteristic of the circuit will become more and more curved up to a definite limit as this resistance is reduced, thereby introducing considerable distortion in the output signal wave. Heretofore, in order to insure markedly increased power output without the accompanying distortion, amplifiers of the push-pull type were employed in conjunction with output transformers having balanced primary windings, but the use of these transformers is not always desirable, especially in circuits where the output currents are of low frequencies or high amplitudes. Even with the use of output transformers the connection of a push-pull amplifier to a line having the sides unbalanced with respect to ground is a problem involving considerable difficulties.

According to the present invention the use of output transformers is avoided and high power efficiency in the vacuum tube amplifier is obtained when the plate circuit is worked over practically the whole characteristic. The distortion thus introduced in the signal wave by the considerable decrease in the vacuum tube output circuit impedance is reduced by impressing a compensating voltage on the grid circuit of the amplifier. The compensating voltage is produced by a second vacuum tube which has its grid circuit connected in parallel and its plate circuit connected in series with the grid circuit of the amplifier. The compensating tube may be arranged to correct for the distortion inherent in the production of the even order multiple frequencies by operating on either the positive or negative portions of the output signal wave, thereby changing the plate current input potential characteristic of the amplifier to be symmetrical on both sides of the zero operating point of the input voltage. Correction for both the odd and even order of multiple frequencies may also be effected by employing the compensating arrangement provided for the negative correction and adjusting the grid biasing batteries of the amplifier and the compensator tube so that the compensating voltage is applied to the input voltage over the entire utilized range of plate current, thereby giving to the amplifier a distortionless or straight line output over the entire range.

Characteristic features of this invention are, eliminating the distortion inherent in the production of even order multiple frequencies in signal waves in the output of a high power vacuum tube amplifier circuit, wherein the output external impedance is not high in respect to the plate circuit impedance; causing the plate current-grid potential characteristic of the amplifier circuit to become symmetrical about the operating point of the normal grid potential by means of compensating voltages being superposed on the input voltages; allowing the filament battery of the amplifier to be connected to earth if required and preventing the unbalance which would ordinarily introduce distortion in the output signals should an amplifier of the push-pull type be used on a grounded output circuit without an output transformer; eliminating the unbalancing effects of capacity produced when the push-pull type of amplifier is used without an output transformer; allowing the use of an unbalanced form of output circuit instead of the balanced transformer type of push-pull amplifier, while giving substantially the same form of output as the push-pull arrangement; and by causing the compensating voltages to become effective at one extremity of the operating range of plate currents rather than at the middle in order to produce a straight line characteristic over the entire utilized range of plate current.

The invention will be described in connection with the accompanying drawings in which:

Fig. 1 illustrates diagrammatically one embodiment thereof for effecting positive current compensation to correct for distortion inherent in the production of even order multiple frequencies;

Fig. 2 illustrates the plate current-input potential characteristic of the power amplifier circuit shown in Fig. 1;

Fig. 3 shows a modification of Fig. 1 whereby negative current compensation is effected to correct for the distortion inherent in the production of even order multiple frequencies;

Fig. 4 shows the plate current-input potential characteristic of the circuit arrangement of Fig. 3;

Fig. 5 shows a modification of Fig. 3 wherein an alternative arrangement for effecting negative current compensation is provided;

Fig. 6 shows the plate current-input potential characteristics of the power amplifier circuits shown in Figs. 1 and 3 when such circuits are designed to provide positive or negative compensation which may be utilized either over the entire operating range or over half the range;

Fig. 7 shows the circuit arrangement of Fig. 1 modified to separate the input voltage, which, for example, may be retransmitted submarine cable signals, into its low and high frequency components so that these components may be compensated in different degrees and then impressed simultaneously on an amplifier;

Fig. 8 shows another modification of Fig. 1, wherein compensation is effected in the output circuit of the amplifier.

Referring to Fig. 1, the signal input voltage is received over conductors 11 and 12 from a generating or reproducing source 13, such as a transmitter, a repeater or an amplifier, and impressed on the grid circuit of a thermionic amplifier 14. Across the signal input circuit 11—12 and in shunt to the main stage amplifier 14 is connected a potentiometer 15, to which is adjustably connected the grid circuit of a compensator thermionic tube 16 so that both circuits are adapted to receive a portion of the signal input voltage. The plate circuit of the main stage amplifier is connected directly to the transmission line 17 and the ground connection 18 and in order to favor power efficiency in the output circuit the plate circuit includes no added impedance between the plate and the transmission line. The plate circuit of the compensator tube forms a part of the grid circuit of amplifier 14. In this arrangement the voltage output of the compensator is added to the signal input voltage in the grid circuit of the amplifier to counteract for even order multiple frequencies appearing in the plate circuit of the amplifier.

The operation of the circuit arrangement shown in Fig. 1 will now be described by referring to Fig. 2, which represents the plate current-input potential characteristic of amplifier 14, before and after compensation of the positive current is effected to correct for dissimilarity of reproduction of positive and negative impulses. The normal or uncompensated characteristic of the amplifier is represented by the curve *abc*, which is indicative of high distortion in the positive current of the output signal wave of the amplifier. Therefore, in order to reduce this distortion and cause the degree of amplification to be approximately the same for both sides of the signal the plate circuit of the compensator tube is connected to the grid circuit of the amplifier by resistance 19, which forms a part of both circuits. The "C" potential furnished by battery 20 in the compensator grid circuit is so adjusted that when no signal input voltage is applied across potentiometer 15 the compensator plate current is reduced to zero value. In a case where a negative signal is applied, the compensator tube grid is carried still farther negative with no compensating effect on the amplifier because the compensator plate current remains at zero value causing thereby the amplifier plate current to follow the portion *ba* of the characteristic. When an increasing positive voltage is applied to the input the compensator plate will draw current which will increase with the input voltage. The voltage drop thus produced across resistance 19 is subtracted from the positive signal input, causing the plate current of the amplifier to follow the curve *bde* to thereby form a new or compensated characteristic. If the compensator stage is properly adjusted the curve *bde* becomes an inverse image of the curve *ba*, thereby producing a characteristic which shows the positive output currents of the amplifier reduced to amplitudes symmetrical with those of the negative output current. This type of compensator is referred to herein as a "positive" compensator since it affects the positive incoming signals.

In Fig. 3 is shown an arrangement known as the "negative" compensator whereby negative current compensation is effected to correct for the type of distortion resulting in the production of even order multiple frequencies. In this arrangement the signal input voltage is received over conductors 11′ and 12′ from a reproducing or generating source 13′ and impressed on the grid circuit of the principal thermionic amplifier 14′. The plate circuit of the amplifier, like that of the arrangement shown in Fig. 1, is connected directly to transmission line 17′ and to ground connection 18′ and includes no impedance. Across the input circuit of the amplifier is connected potentiometer 15′, to which is adjustably connected the grid of a compensator thermionic tube 16′, so that only such of the signal input voltage is impressed on the compensator grid as required. The compensator 16′ is connected in the high side of the signal voltage input circuit, between the potentiometer 15′ and the grid of amplifier 14′, the compensator being adjacent to the amplifier grid. Connected in the plate circuit of the compensator 16′ and in the grid circuit of the amplifier is resistance 19′, which like the resistance 19 in Fig. 1, serves to produce a voltage drop across its opposite ends, but the voltage drop in this case is added to the negative signal impulse whereby the negative amplitude is increased to attain symmetry with the distorted positive amplitude. In this arrangement the filament current for the compensator tube is furnished from an alternating current source 21, although a direct current source might be employed with equal effect.

The operation of the circuit arrangement shown in Fig. 3 will be better understood by referring to Fig. 4, wherein $a'b'c'$ is the uncompensated plate current-input potential current characteristic of the amplifier 14′. The "C" potential furnished by battery 20′ in the compensator grid circuit is so adjusted that when no signal input voltage is applied across potentiometer 15′ the compensator plate current is at zero value. In the case where a positive signal is applied to the conductors 11 and 12 the compensator grid is carried still further negative in respect to the compensator tube filament with no compensating effect on the amplifier because the compensator plate current remains at zero value, thereby causing the amplifier plate current to follow the portion $b'c'$ of the characteristic. When an increasing negative voltage is applied to the conductors 11′—12′ the compensator plate will draw current which will increase with the input voltage. In response to the signals of negative current, the voltage drop produced across resistance 19′ by the compensator plate drawing current makes the amplifier grid more negative than it would be without compensation. Therefore, this compensation is added to the signals of the negative current to correct for the distortion introduced in the amplifier plate current by the production of the even orders of harmonics, thereby causing the amplifier plate current to follow the curve $b'd'$ to form the new or compensated characteristic.

Fig. 5 shows another arrangement for effecting negative compensation to correct for the distortion inherent in the production of even orders of multiple frequencies wherein the compensator tube 22 is connected between the low side of the input and the grid of the amplifier 23. The compensator grid is adjustably connected to the potentiometer 24 and the compensator plate circuit is connected to the amplifier grid through resistance 25. In this arrangement the voltage drop across resistance 25′ is added to the negative input voltage to produce the compensated characteristic $c'b'd'$ shown in Fig. 4.

It may be noted in comparing the compensated characteristics shown in Figs. 2 and 4 that a "positive" compensator effectively reduces amplification of the amplifier stage, while a "negative" compensator increases it. In this manner the characteristics are made substantially symmetrical on both sides of the zero operating point of the input voltage, which allows the circuit arrangement of Fig. 1 to use a higher input voltage for a given output amplitude and the circuit arrangements of Figs. 3 and 5 to require a lower input voltage for the same output amplitude.

It will be noted that the quality of the compensated unbalanced vacuum tube stage is essentially the same as that of a balanced or push-pull stage. However, in certain cases the unbalanced form may be used with greater advantage such as where it is desired to repeat signals to or between submarine cables. In such cases it would be necessary to pass very low frequencies through the vacuum tube amplifier circuit which is grounded in the output circuit and may also be grounded in the input circuit. The low frequency and high output current values involved make transformer coupling of output impractical. Should a push-pull stage be used in these cases the filaments and batteries thereof would be separated from the output ground by one plate circuit impedance and any leakage or capacity between the power supply and the ground connection would unbalance the circuit. The compensated forms of circuits shown in Figs. 1 and 2 have an earthed filament on each of the amplifiers and are not noticeably unbalanced by the capacity or leakage from the amplifier plate batteries. The input voltage to a push-pull stage must be equally divided between the two grids and must be free from ground, but in the compensated arrangements the input is not divided and in the case of the "negative" compensator, the input circuit may be connected to ground.

The principle of grid circuit compensation to correct for plate current distortion may be generally applicable to unbalanced vacuum tube stages where good power efficiency and high quality are required. In this connection it may be advantageous to allow the compensator to operate over the entire range of input rather than over only half the range, as described above. This principle is illustrated in Fig. 6 where $a''b''c''$ is the uncompensated characteristic. Should the zero operating point of the input voltage be fixed at a point f slightly above the point a'' instead of at the mid-point of the characteristic as hereinbefore described, the "positive" compensator may be employed causing the compensated characteristic to follow the straight line fe''. In the case where the zero operating point was fixed at d'' the "negative" compensator would be used and the compensator characteristic would follow the straight line $d''c''$. Using a characteristic such as $d''c''$ with the amplifier grid biased at a point d'', a good quality modulator or detector results.

In order to accurately adjust the compensation to a given circuit a wide latitude of compensator adjustments may be required. In the case of the vacuum tube cable transmitter, fair results were obtained by using a single tube as a compensator, but by arranging two compensator tubes in parallel practically perfect compensation over the entire range was obtainable. In Fig. 7 is shown a positive compensating circuit which has been successfully employed in transmission of submarine cable signals. Since the cable impedance is high to very low frequencies the plate current curvature is more evident on the high signal frequencies than on the low. Therefore, Fig. 7 provides an arrangement whereby the high and low frequencies are introduced to the grid circuit of the amplifier through separate input circuits in a manner described in applicant's U. S. Patent 1,763,880, issued June 17, 1930. In this arrangement advantage is taken of the fact that less compensation may be effected on the low frequencies than on the high and this is accomplished by the use of a high resistance potentiometer placed across the low frequency input and by utilizing any required portion of the voltage drop across this potentiometer for effecting compensation. In the circuit arrangement shown in Fig. 7 terminals 26 and 27 and 28 and 29 are assumed to be connected to the terminals of the low and the high frequency transformers respectively, of the applicant's copending application, supra, thereby providing separate inputs for the low and high frequency components of the signals. Both input voltages are impressed simultaneously on the grid of amplifier 30, which in accordance with the circuit actually employed, consists of twelve vacuum tubes arranged in parallel, the filament current for these vacuum tubes together with that for the compensator tubes being furnishedfrom an alternating current source 31. Across the low frequency input terminals 26 and 27 and the high frequency input terminals 28 and 29 are respectively connected potentiometers 32 and 33, the potentiometer 32 being of a high resistance so as not to appreciably affect the voltage supplied from a high impedance circuit connected to terminals 26 and 27. Adjustably connected to the potentiometers are the grid circuits of compensator tubes 34 and 35, which are arranged in parallel. It will be noted from the relative positions of the taps of the potentiometers that less compensation is used on the low frequency components of the signaling voltage than on the high frequency components. In the compensator plate circuit which is common to both tubes 34 and 35 and which is included in the grid circuits of amplifier 30, resistance 36 serves to produce the voltage drop for effecting the compensation in the grid circuit in the same manner as resistance 19 in Fig. 1 described above.

The other modification of Fig. 1 is shown in Fig 8 wherein compensation is effected in the output circuit of the amplifier instead of in the input or grid circuit. The input voltage is impressed directly on the grid of amplifier 41 and the resulting plate current is impressed on the grid circuit of compensating tube 42 to cause a compensating voltage drop across the resistance 43 sufficient to effect the necessary compensation. This arrangement produces the same effect on the plate current-grid potential characteristic of the amplifier as is shown in Fig. 2.

What is claimed is:

1. An amplifier system having a normally curved relation between input voltage or current and output voltage or current provided with means for causing the relation to be straight or suitably modified over at least a part of the working range comprising a supplementary amplifier of curved characteristic, means for supplying thereto a portion of the input voltage or current, and means for supplying from said supplementary amplifier a suitably amplified voltage or current to the circuit of said principal amplifier in a direction so that the curvatures of the two characteristics result in a modification of the curvature of the characteristic of the amplifier system so that the distortion thereof is reduced.

2. In a signaling system comprising a space discharge amplifier having an input and an output circuit for utilization of signals, signal producing means connected to the input circuit of said amplifier, means for utilizing a part of the input voltage from said signal producing means to effect compensation in the output of said amplifier to produce a sym-

metrical signal wave of positive and negative amplitudes in said output circuit.

3. In a signaling system comprising a space discharge amplifier having an unsymmetrical characteristic, signal producing means connected directly to the grid circuit of said amplifier, and a second space discharge amplifier operatively connected to supply energy to said first named amplifier and to receive energy directly from said signal producing means, said second amplifier being effective to superpose compensating voltages on a received impulse in the electrode circuit of said first named amplifier to thereby produce an outgoing signal wave of symmetrical positive and negative amplitudes.

4. In a signaling system comprising a transmission line, a vacuum tube amplifier having its output circuit connected directly to said line, wave-producing means connected to the grid of said amplifier, a second vacuum tube having its grid circuit connected in parallel and its plate circuit connected in series with the grid circuit of said amplifier, a source of power for the filament of said amplifier, and means for connecting said source to ground without introducing distortion in the output waves.

5. A conductive line system having one side of the line at ground potential, a space discharge tube amplifier having input and output circuits, one of said circuits being connected to said line, the terminal of said circuit adjacent said line being grounded, in combination with the auxiliary discharge tube for supplying to said space discharge tube voltages derived from waves to be amplified for modifying the characteristic of said space discharge tube.

6. An amplifier circuit, a space discharge device normally operating on a curved portion of its amplification characteristic, another space discharge device having a curved characteristic, means for impressing a part of the input voltage of the first mentioned device upon the input circuit of the second mentioned device and means for impressing the output voltage of the second mentioned device on the input voltage of the first mention device in such a manner that the characteristic of said second mentioned device has a compensating effect upon a part of said portion of the characteristic of said first mentioned device to impart a substantially symmetrical amplification characteristic to said amplifier circuit.

7. An amplifier circuit comprising an amplifying device having at normal load an unsymmetrical amplification characteristic, a rectifying device having a curved input-output characteristic, means for connecting the input and the output circuits of said rectifying device in the input circuit of said amplifying device to increase the symmetry of the characteristic of said circuit by combining the characteristic of said rectifying device with that of said amplifying device.

8. An amplifier circuit for transmission of a signal impulse, a first space discharge device included in said circuit having a curved amplification characteristic, a second space discharge device having a curved amplification characteristic, means for impressing on said second device potential variations produced by said signal impulse to produce a distorted impulse, circuit means for impressing said distorted impulse upon said amplifier circuit in such a manner that the curved characteristics of said devices are combined to reduce the curvature of the amplification characteristic of said amplifier circuit.

In witness whereof, I hereunto subscribe my name this 16th day of July, 1928.

EVERETT T. BURTON.